Searches for First Generation Leptoquarks in the eejj channel

Simona Rolli

TUFTS University

Abstract

We report on a search for first generation scalar leptoquarks, S1, done using 70.2 pb^{-1} of run II data taken at $\sqrt{s}$ = 1960 GeV. Leptoquarks are assumed to be pair produced and to decay into a lepton and a quark of the same generation. We will focus on the signature represented by two energetic electrons and two jets. We set an upper limit at 95% CL on the production cross section as a function of the mass of the leptoquark. By Assuming (β = Br(LQ$\rightarrow$eq)) = 1 and using the NLO theoretical estimate we reject the existence of scalar leptoquarks with mass below 233 GeV/c^2 (no systematic uncertainty included) and 223 GeV/c^2 (adding a 30% blind systematic uncertainty).

Introduction

Leptoquarks are hypothetical color-triplet particles carrying both baryon and lepton quantum numbers and are predicted by many extension of the Standard Model as new bosons coupling to a lepton-quark pair[1]. Their masses are not predicted. They can be scalar particles (spin 0) or vector (spin 1) and at high energy hadron colliders they would be produced directly in pairs, mainly through gluon fusion or quark antiquarks annihilation. In figure 1 a typical production diagram is reported.
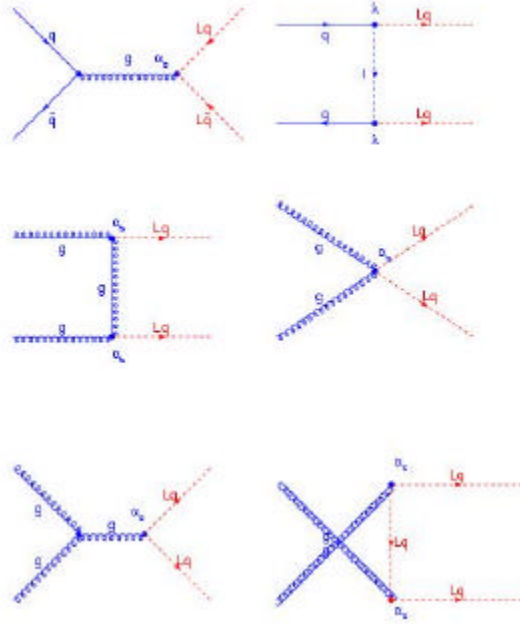
Figure 1

The couplings of the leptoquarks to the gauge sector are predicted due to the gauge symmetries, up to eventual anomalous coupling in the case of vector leptoquarks, whereas the fermionic couplings λ are free parameters of the models. In most models leptoquarks are expected to couple only to fermions of the same generations because of experimental constraints as non observation of flavor changing neutral currents or helicity suppressed decays. The production cross section for pair produced scalar LQ has been calculated up to NLO[1].The decay angular distribution of scalar leptoquarks is isotropical. The NLO cross section at $\sqrt{s}$ = 1960 GeV is reported in Table 0 for values of the LQ mass between 200 and 320 GeV/c^2. The scale has been chosen to be $Q^2 = M_{LQ}^2$ and the set of parton distribution functions is CTEQ4M[].

M_{LQ} (GeV/c^2)	σ(NLO) [pb]
200	0.265E+00
220	0.139E+00
240	0.749E-01
260	0.412E-01
280	0.229E-01
300	0.129E-01
320	0.727E-02

Table 1

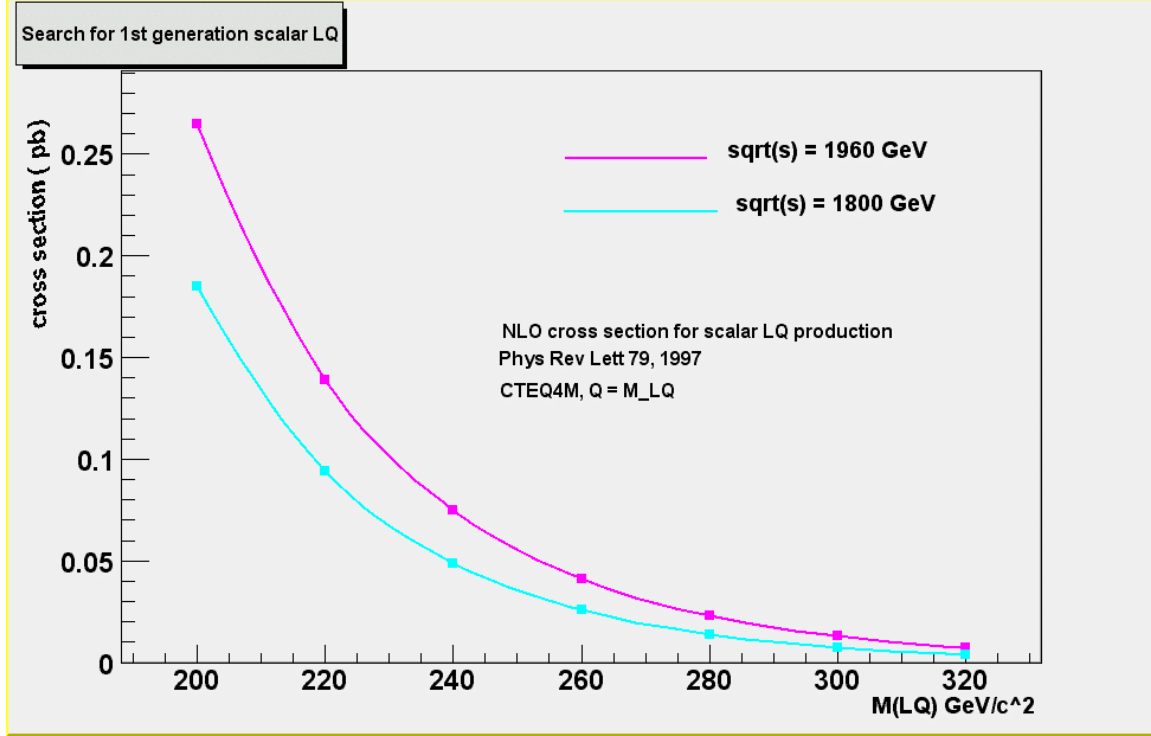The cross section compared with the one at 1.8 TeV is reported in Figure 2

Figure 2

This analysis is focused on the search for first generation scalar leptoquarks S1, pair produced and decaying into eejj. The analysis strategy is a repetition of the run I analysis[2,3] and at this time improvements and optimization of cuts are not performed.

Current Limits

In table 1 the current limits on the first generation LQ are reported, both from CDF and D0.

1st Gen	β	Scalar (GeV/c²)	Vector – minimal coupling(GeV/c²)	Vector – Yang-Mills coupling(GeV/c²)
D0	1	225(242)	292	345
	0.5	204	282	337
	0	98	238	298
CDF	1	220 (242)	280	330
	0.5	202	265	310

Table 2 – current limits on first generation LQ from the TeVatron

3

Data sample and electron identification

The data sample used for this analysis is *btop0g* (inclusive electrons) stripped for the Top group from the inclusive high pt electron datasets. The sample is described in[4].
The L3 trigger dataset *(bhel08)* was reconstructed with offline version 4.8.4 and the events were filtered into *btop0g* using the following loose cuts:
- CdfEmObject.Pt > 9.0 GeV
- CdfEmObject.etCalMin > 18.0 GeV
- CdfEmObject.delX < 3.0
- CdfEmObject.delZMin < 5.0
- CdfEmObject.E/P < 4.0
- CdfEmObject.lshr < 0.3
- CdfEmObject.hademMax < 0.125

For the ELE_70 trigger:

- CdfEmObject.Pt > 15.0 GeV
- CdfEmObject.etCalMin > 70.0 GeV
- CdfEmObject.delX < 3.0
- CdfEmObject.delZMin < 5.0

A REMAKE version of *b0topg* was made where all the calorimeter-dependent objects were dropped in input as well as electron and muon reconstruction objects. The 4.8.4 tracks were refitted (using TrackRefitModule) without L00 hits, and electron and muon objects were remade picking up the refit tracks and run-dependent calorimeter corrections. The sample is on fcdfsgi2 in
/cdf/data54/ewk/data/highpt_491/Inclusive-ele_484_REMAKE and corresponds to an integrated luminosity of 70.2 pb^{-1} (good runs between March 23 – January 12, 2003 – runs 141544 to 156487, selected following the *good run list without Silicon* used by the W mass group).

The sample has been reduced by requiring events with at least 2 CdfEmObjects (with trackid != 0), satisfying the following criteria:
- E_T > 25 GeV
- p_t > 10 GeV
- hadem <= 0.055 + 0.00045 * E
- E/p < 4 (for E_T < 200 GeV)
- |DeltaX | < 3.0 cm
- |DeltaZ | < 5.0 cm
- lshr <= 0.2

- fiducial == 1

Of the 2 electrons one is required to have

- isolation ratio < 0.1 (tight) while the second can have isolation ratio < 0.2 (loose).

These electron identification cuts are also used in the Z' [5,6] analysis and the efficiencies are reported in Table 3.

		CDF Run II Preliminary ($72 \, \mathrm{pb}^{-1}$)		
Cut	Number of candidate events	Number of background	Efficiency (%)	
$Iso < 0.1$	2101	118	97.7 ± 0.2	
$Iso < 0.2$	2329	274	99.6 ± 0.1	
E_{had}/E_{em} $< 0.055 + 0.00045 \times E$	2532	496	99.1 ± 0.2	
$E/P < 4.0$ (for $E_T < 200$)	2732	700	99.0 ± 0.2	
$|\Delta X| < 3.0$	2808	804	98.2 ± 0.2	
$|\Delta Z| < 5.0$	2902	858	99.3 ± 0.1	
$L_{shr} < 0.2$	2482	406	100.0 ± 0.1	
Tight central overall(ε_T)	1717	36	89.6 ± 0.5	
Loose central overall(ε_L)	1787	46	91.2 ± 0.5	
$\varepsilon_{CC}(= 2 \cdot \varepsilon_T \cdot \varepsilon_L - \varepsilon_T^2)$			83.2 ± 0.8	

Table 3 – Efficiency for CC electrons as from ref[5,6]

Acceptance calculation

We generated 5000 events samples of scalar leptoquarks pair decaying into *eq* for M_{LQ} in the range 200 to 320 GeV/c^2 using Pythia[10]. The samples have been generated to simulate realistic beam conditions, emulating run number 151435 and using the following talk-to for the full beam position:

```
talk GenPrimVert
 BeamlineFromDB set false
 sigma_x      set 0.0025
 sigma_y      set 0.0025
 sigma_z      set 28.0
 pv_central_x  set -0.064
 pv_central_y  set 0.310
 pv_central_z  set 2.5
 pv_slope_dxdz set -0.00021
 pv_slope_dydz set 0.00031
exit
```

The samples were generated with $Q^2 = M_{LQ}^2$ and the MRS-R2 pdf set[12]. The samples were simulated with cdfSim version 4.9.1 and Production 4.9.1 was ran on them.
In figure 3-5 the E_T distributions of the decay products of the Leptoquark are plotted, for different values of the mass of the leptoquark and after reconstruction.
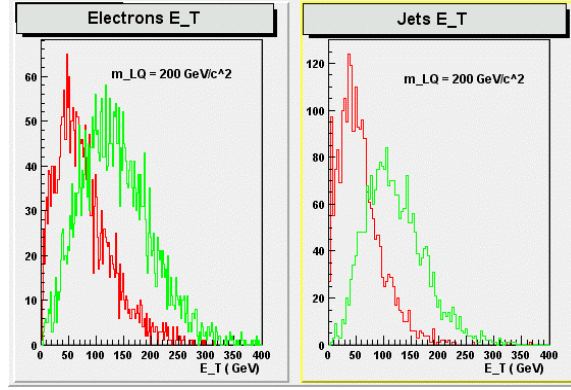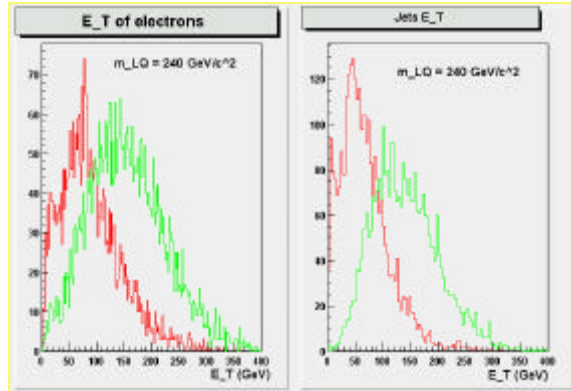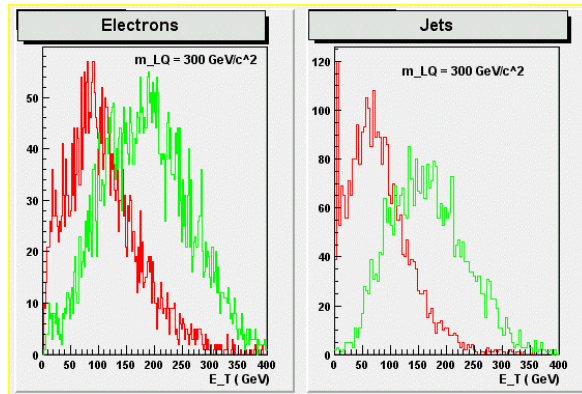
Figure 3

Figure 4

Figure 5

The analysis cuts are a combination of the previous run I analysis:

- 2 electrons with $E_T > 25$ GeV
- 2 jets with $E_T(j1) > 30$ and $E_T(j1) > 15$ GeV
- Removal of events with $76 < M_{ee} < 110$
- $E_T(j1) + E_T(j2) > 85$ GeV && $E_T(e1) + E_T(e2) > 85$ GeV
- $\sqrt{((E_T(j1) + E_T(j2))^2 + (E_T(e1) + E_T(e2))^2)} > 200$ GeV

The last cut was shown in run I to discriminate between signal and background, as shown in Figure 6. In Figures 7 the sum of the electrons E_T is plotted against the sum of the 2 jets E_T for signal, DY + 2 jets and tt after selecting 2 electrons and 2 jets.
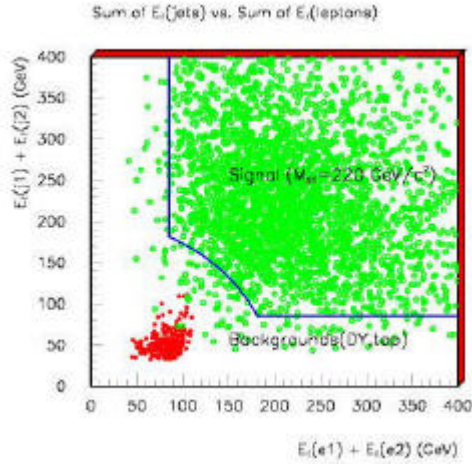

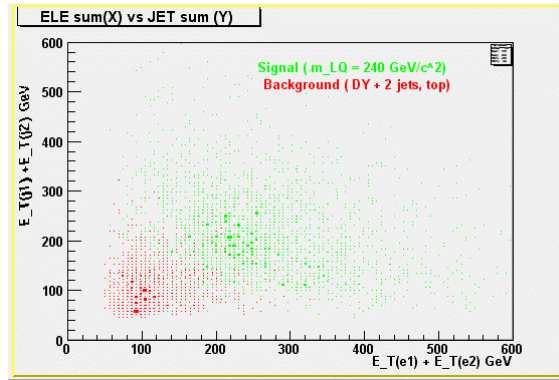Figure 6 – Sum of E_T(jets) vs Sum of E_T(electrons) – run I simulation

Figure 7 – Sum of E_T(jets) vs Sum of E_T(electrons) – run II simulation

The analysis cuts efficiencies are calculated relatively to the number of events having 2 cdfEmObjects with track id different from 0 (to exclude photons), matching the generator level electrons. They are reported in Figure 8 and Table 4. The efficiencies are then folded with the electron ID efficiencies reported in Table 2, the z vertex cut efficiency[7] (0.952 ±001 (stat) ±005 (sys)) and the trigger efficiency[9] (0.991 ±001) . We have verified that the electron identification efficiencies for 2 central electron for the signal ($M_{LQ} = 240$ GeV/c^2) are of the same order of magnitude of the ones calculated from real Z data. $\varepsilon_T = 0.875 \pm 0.006$, while $\varepsilon_L = 0.882 \pm 0.006$. The combined efficiency is: $2\varepsilon_T\varepsilon_L - \varepsilon_T\varepsilon_T = 0.777 \pm 0.008$. The slightly lower efficiency can be attributed to a reduced efficiency of the isolation cut in an environment denser in jets than Z→e$^+$e$^-$.

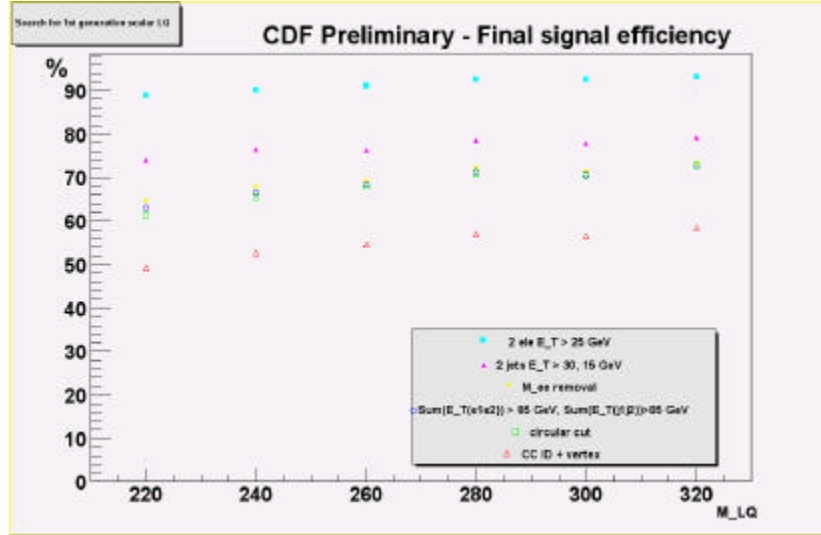Figure 8 – kinematical efficiency as function of the leptoquark mass

M_{LQ} (GeV/c^2)	200	220	240	260	280	300	320
2 ele with $E_T > 25$ GeV	0.873±0.006	0.888±0.005	0.901±0.005	0.911±0.005	0.925±0.004	0.924±0.004	0.932 ±0.004
2 jets with $E_T > 30$, 15 GeV	0.691±0.009	0.707±0.007	0.731±0.008	0.722±0.007	0.739±0.007	0.739±0.007	0.751± 0.006
M_{ee} removal cut	0.600±0.009	0.615±0.008	0.646±0.008	0.653±0.008	0.674±0.008	0.676±0.008	0.693± 0.008
$\Sigma(E_T(ele_i)) > 85$ GeV & $\Sigma(E_T(jet_i)) > 85$ GeV	0.557±0.009	0.583±0.008	0.626±0.009	0.638±0.008	0.658±0.008	0.665±0.008	0.688± 0.008
$\Sigma(E_T(ele_i)+ E_T(jet_i)) > 200$	0.535±0.009	0.571±0.008	0.619±0.008	0.636±0.008	0.656±0.008	0.664±0.008	0.687± 0.008

Table 4 - kinematical efficiency as function of the leptoquark mass

The expected number of events of signal in 72 pb^{-1} given the above efficiencies and the NLO theoretical cross section for different value of the renormalization/factorization scale, is reported in the Table below:

Mass (GeV/c^2)	n Theory CTEQ4M (pb) $Q^2 = M^2_{LQ}/4$	n Theory CTEQ4M (pb) $Q^2 = 4M^2_{LQ}$
200	8.76824	7.0692
220	4.89033	3.95113
240	2.86058	2.30601
260	1.61727	1.29669
280	0.929346	0.743477
300	0.530579	0.421453
320	0.311095	0.244905

Table 5 – Expected number of signal events in 72 pb^{-1}

After our selection cuts 0 events are left. In Table 5 we report the number of events surviving each kinematical cut.

Number of events with 2 electrons with $E_T > 25$ GeV	1970
2 jets with $E_T(j1) > 30$ GeV and $E_T(j1) > 15$ GeV	21
removal of events with $76 < M_{ee} < 110$ GeV	7
$E_T(j1) + E_T(j2) > 85$ GeV && $E_T(e1) + E_T(e2) > 85$ GeV	2
$\ddot{\mathbf{O}}((E_T(j1) + E_T(j2))^2 + (E_T(e1) + E_T(e2))^2) > 200$ GeV	0

Table 5 – List of events passing the selection cuts

Backgrounds

The main backgrounds is due to $\gamma/Z\rightarrow ee$ events accompanied by jets due to radiation. The main component of this background is eliminated by cuts on M_{ee} around the mass of the Z boson and the ΣE_T cuts. However there are still events from the DY continuum and Z events that fail the cuts due to mis-measurement. We studied the distribution of this background by generating the process Z + 2 jets with Alpgen[11] and using the MC parton generator mcfm[13] to obtain the NLO cross section.
Another source of background is represented by tt production where both the W decay into eν. Other backgrounds from bb, Z$\rightarrow\tau\tau$, WW are expected to be negligible due to the electron isolation and large electron and jet transverse energy requirements. The expected number of DY + 2 jets events in 70.2 pb^{-1} is 3.13 $\pm$ 2.8. The expected number of tt

events is 0.25 ± 0.03 events. To normalize simulated events to data we used the theoretical cross section for tt, $\sigma(tt) \times Br(W \rightarrow e\nu) = 0.0739$ pb, and the theoretical cross section for $Z/\gamma + 2$ jets.

The total number of expected events of background is 3.39 ± 3.15 .

We also checked that the events we are left before requiring the jets and the following analysis cuts are consistent with the production of Z.
Z boson candidates are selected by requiring $70 \text{ GeV} < M_{ee} < 110 \text{ GeV/c}^2$ (as in the Z' analysis) and the cross section is calculated from the following formula:

$$\mathbf{s} \,!\text{Br} \,(pp \rightarrow Z \rightarrow e^+ e^-) = (N_Z - N_{BG})/(A_Z \times \varepsilon_{ID} \times \varepsilon_{trig} \times \varepsilon_{z0} \times L)$$

Using the values listed in the Table below we obtain for the Z cross section a value of 270.50 ± 15.3 pb. In Figure 9 the Z mass distribution is plotted.

Acceptance	$11.5 \pm 0.7\%$
ID efficiency	$83.2 \pm 0.5\%$
Trigger Efficiency	$99.9 \pm 0.1\%$
z_0 efficiency	$95.2 \pm 0.5\%$
Observed number of events	1806
Estimated background	34.8 ± 21.1
Integrated Luminosity	$72. \pm 4.32$

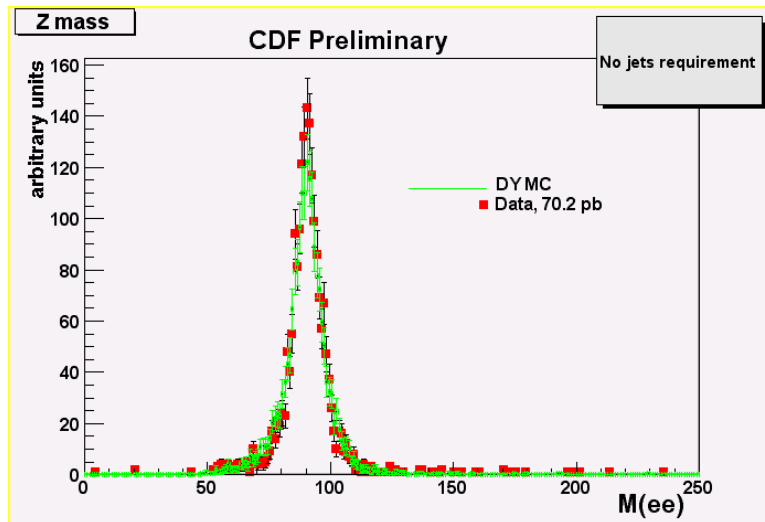Table 6 – parameters used in the calculation of the Z cross section

Figure 7 – *Dielectron invariant mass distribution for MC and data. Data and generated MC have been normalized to each other in the Z mass window (70-110 GeV/c^2) to take into account the different luminosity. No jets requirement and successive LQ analysis cuts have been applied to this event selection*

Systematic Uncertainty

The following systematic uncertainty is considered:
- Luminosity: 6%
- Acceptance
    - pdf 4.3% (from run I)
    - statistical error of MC 2.2%
    - Jet energy scale (relative, time dependent and energy scale corrections applied) $< 1\%$
- Electron ID efficiency[5,6]
    - statistical error of $Z \rightarrow e^+e^-$ sample: 0.8%
    - energy scale : 3.7%
- Event vertex cut : 0.5%[7]

Adding the above systematic uncertainty in quadrature will give a total systematic uncertainty of about 9%.

Cross section Limit

The production cross section σ of the process S1S1$\rightarrow$ eejj can be written as follows:

$$\sigma \times Br(S1S1 \rightarrow eejj) = \sigma \times \beta^2 = N/(\varepsilon \times L),$$

where N is the number of observed events on data after our selection, ε is the total selection efficiency as a function of M_{LQ} and L is the integrated luminosity. As we found no candidate events in our selection, we set a 95% C.L. upper limit on the cross section as a function of M_{LQ} defined as:

$$\sigma^{lim} = N^{lim}/(\varepsilon \times L \times \beta^2)$$

The limit was calculated using bayes[14].

In Table 7 we report the values of the limit cross sections in eejj for each M_{LQ} and for $\beta = 1$ and the theoretical calculations at NLO for pair production of scalar LeptoQuarks at the TeVatron done using CTEQ4M pdf and for different choices of the scale. In Figure 8 the limit cross-section as function of M_{LQ} is compared with the theoretical expectations for $\beta = 1$. At the intersection point between experimental and theoretical curves we find the lower limit on M_{LQ} at 230 GeV/c^2.

Mass (GeV/c^2)	95%CL σ (pb)	σ Theory CTEQ4M (pb) $Q^2 = M^2_{LQ}/4$	σ Theory CTEQ4M (pb) $Q^2 = 4M^2_{LQ}$
200	0.101055	0.2890	0.2330
220	0.0945771	0.1510	0.1220
240	0.0872671	0.0815	0.0657
260	0.0850378	0.0449	0.0360
280	0.0823698	0.0250	0.0200
300	0.0813719	0.0141	0.0112
320	0.0786428	0.00799	0.00629

Table 7 – *Values of the upper limits at 95% CL of the production cross section of first generation leptoquarks decaying into eejj channel as a function of M_{LQ}. The last 2 columns on the right report the result of the theoretical calculations at Next-To-Leading order with CTEQ4M for different choices of the scale, multiplied by a factor $b \acute{} b = 1$.*
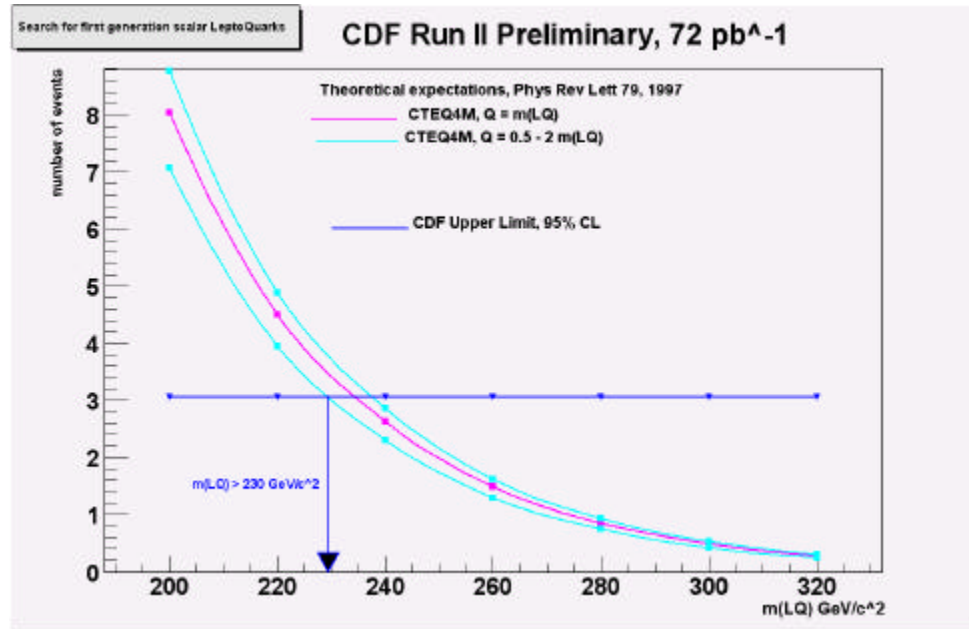
Figure 8 - *Limit cross section as a function of M_{LQ} compared with the theoretical expectations calculated at NLO accuracy. At the intersection points between experimental and theoretical curves we find a lower limit on M_{LQ} at 230 GeV/c^2*

Conclusions

We have presented a preliminary 95% CL cross section lower limit as a function of M_{LQ}, for leptoquarks decaying with 100% branching ratio into eq and we have compared it to the theoretical predictions for leptoquark pairs production at the TeVatron. By using the theoretical estimate, we can reject the existence of a scalar leptoquark with mass lower than 233 GeV/c^2 for $\beta = 1$ (no systematic uncertainty included at this time).

Acknowledgements

I want to thank Federica Strumia and Carla Pilcher for various comments and suggestions regarding the run I analysis. I also want to thank Stephan Lammel for the patience he showed when answering many questions…

References

1) Pair Production of scalar LeptoQuarks at the TeVatron, M. Kramer et al., Phys Rev Lett 79, 341, 1997.
2) Search for first generation leptoquarks pair production , A. Amadon, C. Grosso-Pilcher and F. Strumia, CDF/ANAL/EXOTIC/CDFR/4126, July 1997
3) Searches for First Generation Leptoquarks in the eeqq and enuqq channels, Federica Strumia, Allan Clark,Lorenzo Moneta, Xin Wu and Carla Grosso-Pilcher CDF/ANAL/EXOTIC/CDFR/4873
4) Description of data samples for Top and Electroweak groups for Winter 2003, Evelyn J. Thomson, CDF/DOC/TOP/PUBLIC/6265
5) Randall-Sundrum resonance searches in high mass Run I dilepton data, Tracey Pratt, Koji Ikado, Kaori Maeshima, Todd Huffman CDF/ANAL/EXOTIC/CDFR/6117
6) Search for Resonances in High Mass Dielectron Koji Ikado, Kuni Kondo, Kaori Maeshima, Tracey Pratt CDF/ANAL/EXOTIC/CDFR/6080
7) Event |Zvtx| < 60 cm Cut Efficiency for Run II W.K. Sakumoto and A. Hocker CDF/ANAL/ELECTROWEAK/CDFR/6331

8) Z^{0} to electrons Cross Section measurement with Run II data
   Young-Kee Kim, Giulia Manca
   CDF/ANAL/ELECTROWEAK/CDFR/6281

9) Trigger Efficiencies for High P_T Electrons
   Young-Kee Kim, Jason Nielsen, Lauren Tompkins, Greg Veramendi
   CDF/DOC/ELECTRON/CDFR/6234

10) http://www.thep.lu.se/~torbjorn/Pythia.html

11) http://mlm.home.cern.ch/mlm/alpgen/

12) http://consult.cern.ch/writeup/pdflib/

13) http://mcfm.fnal.gov/

14) Poisson Upper Limits Incorporating Uncertainties in Acceptance and
    Background   John Conway Kaori Maeshima
    CDF/PUB/EXOTIC/PUBLIC/4476